ISTITUTO NAZIONALE DI FISICA NUCLEARE

Sezione di Milano

INFN/TC-85/14
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dei Laboratori Nazionali di Frascati

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RESPONSE FUNCTIONS OF AN X-RAY DETECTING SYSTEM FOR SPECTRAL ANALYSIS OF THERAPEUTIC BEAMS

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ABSTRACT

Direct measurements of the bremsstrahlung spectra produced by therapeutic accelerators are usually impossible due to the high fluxes involved. We plan to use an indirect method based on compton scattering on little target.

As a first step a detailed study of the response functions of a shielded Ge(Li) detector, utilizing Monte Carlo calculations, has performed for incident energies from 0.1 to 1 MeV. Theoretical results for the response functions have been compared with the experimental data obtained with monochromatic sources.

An adequate deconvolution technique has been developed to analyze continous or discrete non monochromatic spectra.

To determine all the response functions, that one needs to know, for this procedure a suitable interpolation of the calculated response functions has been carried out.

The results obtained with a ^{226}Ra source are shown and discussed.

1. - INTRODUCTION

The importance of a detailed knowledge both of spectral composition and geometry of therapeutic X-ray beams is well known (1,2).

In fact, to evaluate the absorbed dose, one must know the energetic and spatial distribution of the X-ray beam. On the other hand the direct measurements of the bremsstahlung spectra produced by therapeutic accelerators, is almost impossible due to the high fluxes involved. The evaluations, obtainable from theoretical calculations, are not completely reliables, as it appears from the comparison with dosimetric measurement in phantoms.

We are developing a method of measurement of bremsstrahlung distributions, obtained from electron beams accelerated up to 20 MeV in therapeutic accelerators.

Dose measurements allow to establish that in these conditions, one has fluxes up to 10^9 photons/s cm^2. As a consequence of these high fluxes, it is not possible to make a direct measurement of the X-ray beams. So, we plan to use an indirect method of measurement based on the Compton scattering from a small target scanning the beam.
The diffused radiation has an intensity much lower than the incident one; moreover its energy, by a convenient choice of the detection angle with respect to the primary beam direction, can be reduced to an energy range suitable for the detecting system.

However, in general, it is not possible to reconstruct directly the incident spectrum from the detected one: for the reconstruction of the "real" photon spectrum, one has to develop an adequate deconvolution technique. This is the first fondamental step to be followed for the detailed analysis of the deformation effects on the spectra due to the Compton scattering on the scanning target.

A crucial point in this kind of analysis is the determination of the response function of the detector.

This paper is devoted to the description of the techniques developed to reconstruct the "real" spectrum from the one measured with a shielded Ge(Li) detector for incident energies from 0.1 to 1 MeV.

2. - DECONVOLUTION TECHNIQUE

Fig. 1 shows a generic response function of a Ge(Li) detector irradiated with a monochromatic gamma beam. Because the energy range of interest is below the value at which pair production is significant, the spectrum results only from the combined effect of photoelectric absorption, corresponding to those events that lose all their energy in the detector, and Compton scattering. In this effect there is the creation of a recoil electron and a scattered gamma ray, with the partition of energy between the two, depending on the scattering angle. Normally a continuum of energy can

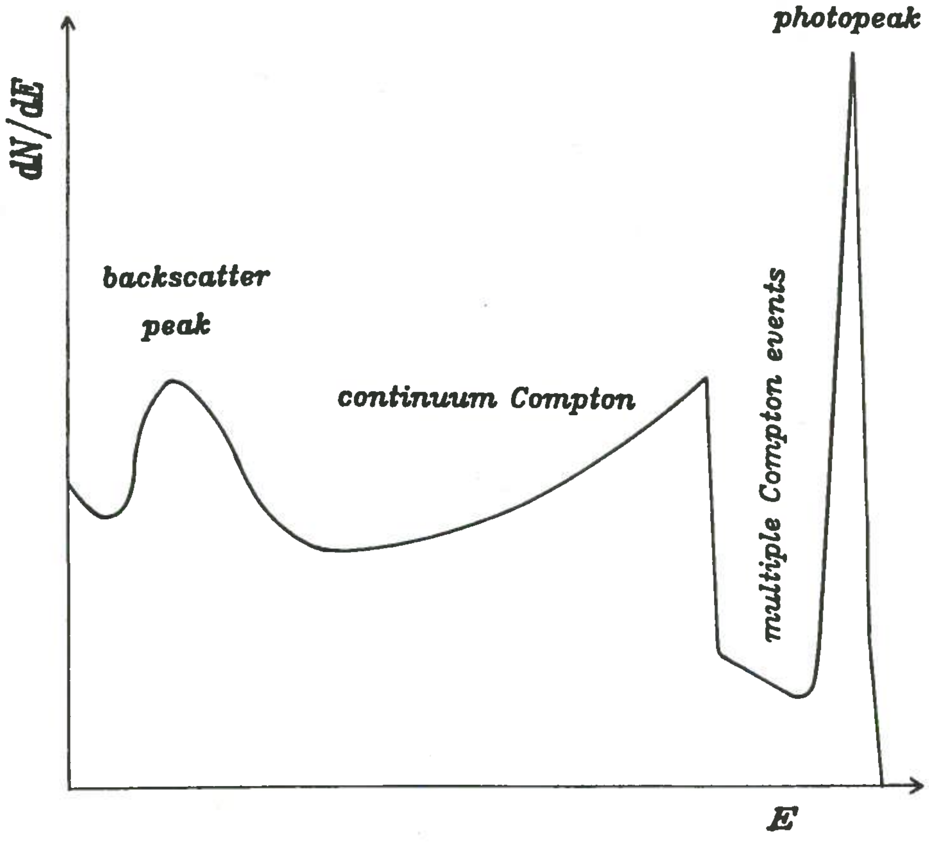

Fig. 1 The pulse- heigh distribution of a solid state detector, invested by a monochromatic photon beam.

be transferred to the electron, ranging from zero up to the maximum, given by:

$$E_e = h\nu \frac{2h\nu/m_oc^2}{1 + 2h\nu/m_oc^2} \qquad (1)$$

where $h\nu$ is the energy of the incident gamma ray
m_o is the rest mass energy of the electron

The peak near 0.2 - 0.25 MeV is called "backscatter peak" and is caused by gamma rays from the source which have first interacted by Compton scattering in one of the matherials sorrounding the detector.

Due to the fact that the response functions for different energies are different in shape, it is not possible to use a deconvolution procedure based on an analytic transformation like the Fast Fourier Transform of the spectrum. So we have utilized the following procedure.

If the spectrum has been collected in a finite number of channels, one can assume that in general the content of each channel is due to the photoelectric effect for the corresponding energy, added to a background due essentially to the response functions determined at higher energies.

If N is the last channel of the measured spectrum with counts not equal to zero, its C_N content is only due to the photoelectric peak, corre-

sponding to photons of maximum energy in the beam. To eliminate, at lower energy, the Compton contribution related to these photons, the corresponding response function, suitably normalized (see **Relation 2**), is subtracted from the collected spectrum.
After this correction, the content C_i' of i-th channel is determined through the relation:

$$C_i' = C_i - F_i * C_N/F_N \quad (2)$$

where C_i (i = 1,2,...,N-1) is the content of i-th channel of the measured spectrum;
F_i (i = 1,2,...,N) is the value of the response function.

Now the content C'_{N-1} of the (N-1)-th channel does not contain the contribution of background from higher energies and so corresponds to the true number of photons of that energy in the primary beam.

An iterative procedure of subtraction applied from the N-th channel to the first one, eliminates the background and allows to obtain the true shape of the spectrum. **Fig 2** shows the sequence of this procedure for the N-th channel.

3. - RESPONSE FUNCTIONS

For the application of the described deconvolution procedure, one needs to know a large number of response functions, distributed in the energy range of the primary beam with steps comparable to the wanted resolution.

To solve this problem, as a first approch, we have constructed the response functions of a shielded Ge(Li) detector to monochromatic photon beams, in the energy range from 0.1 to 1. MeV, utilizing a Monte Carlo program (3).

The program simulates the random generation of N monoenergetic photons in the area of the source and simulates the possible interactions of the photons in the detector material (photoelectric and Compton effect) following the "history" of all the particles involved (photons and electrons).

The goodness of the program has been tested, comparing the values of the photopeak efficiency, calculated with the Monte Carlo program for the detector and the geometry experimentally used, with an experimental efficiency curve.

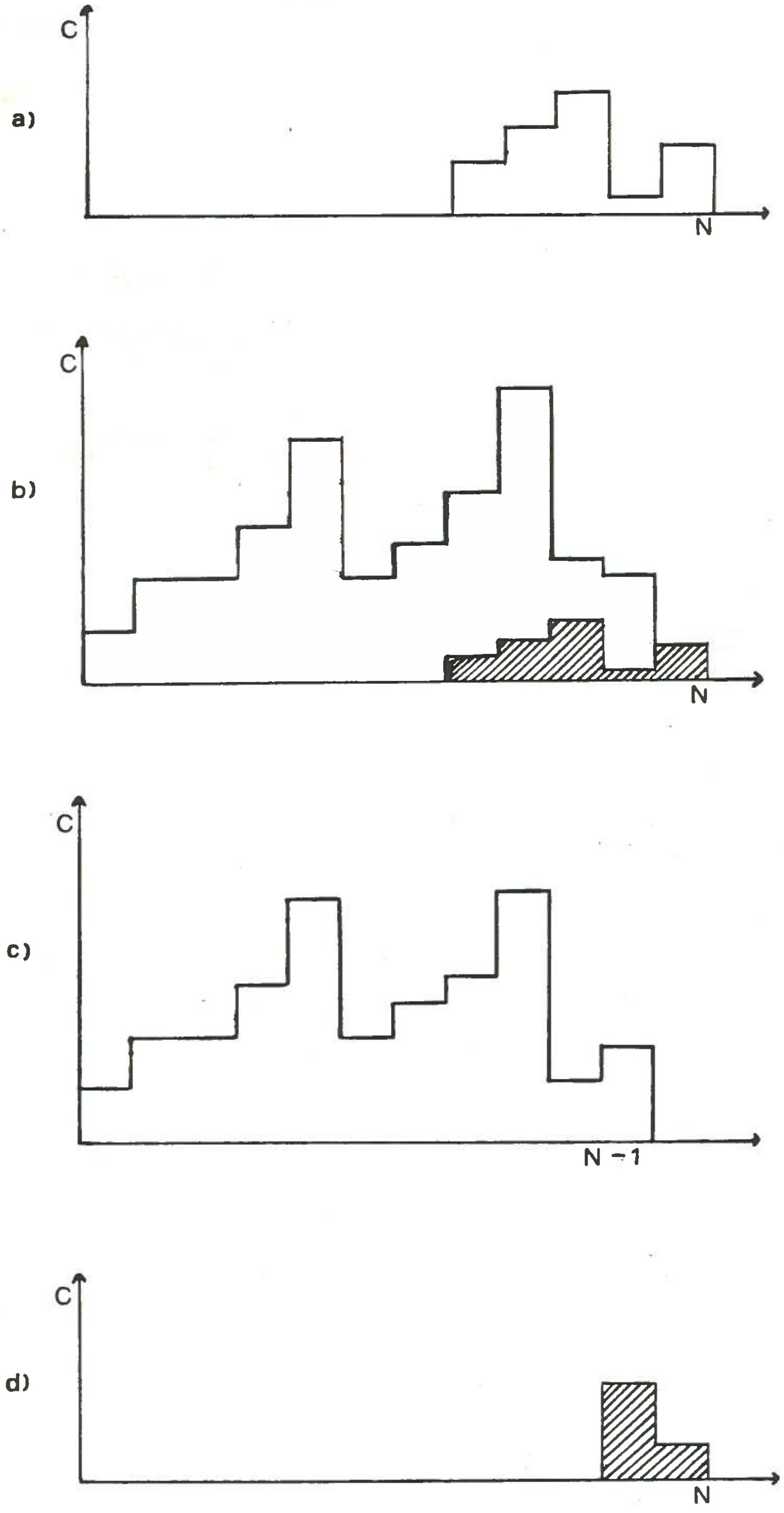

Fig. 2 Procedure of subtraction:
a) response function of the N-th channel;
b) original spectrum and the response function suitable normalized;
c) the spectrum after the first subtraction;
d) N-th and (N-1)-th channels without the background contribution.

Moreover it has been compared the shape of the Compton effect contribution, detected for a ^{137}Cs monochromatic source and the corresponding response function. The calculated spectrum is normalized on the basis of the ratio between the areas of the two photopeaks.

The comparison, shown in **Fig. 3** is good, except for the backscattering contribution.

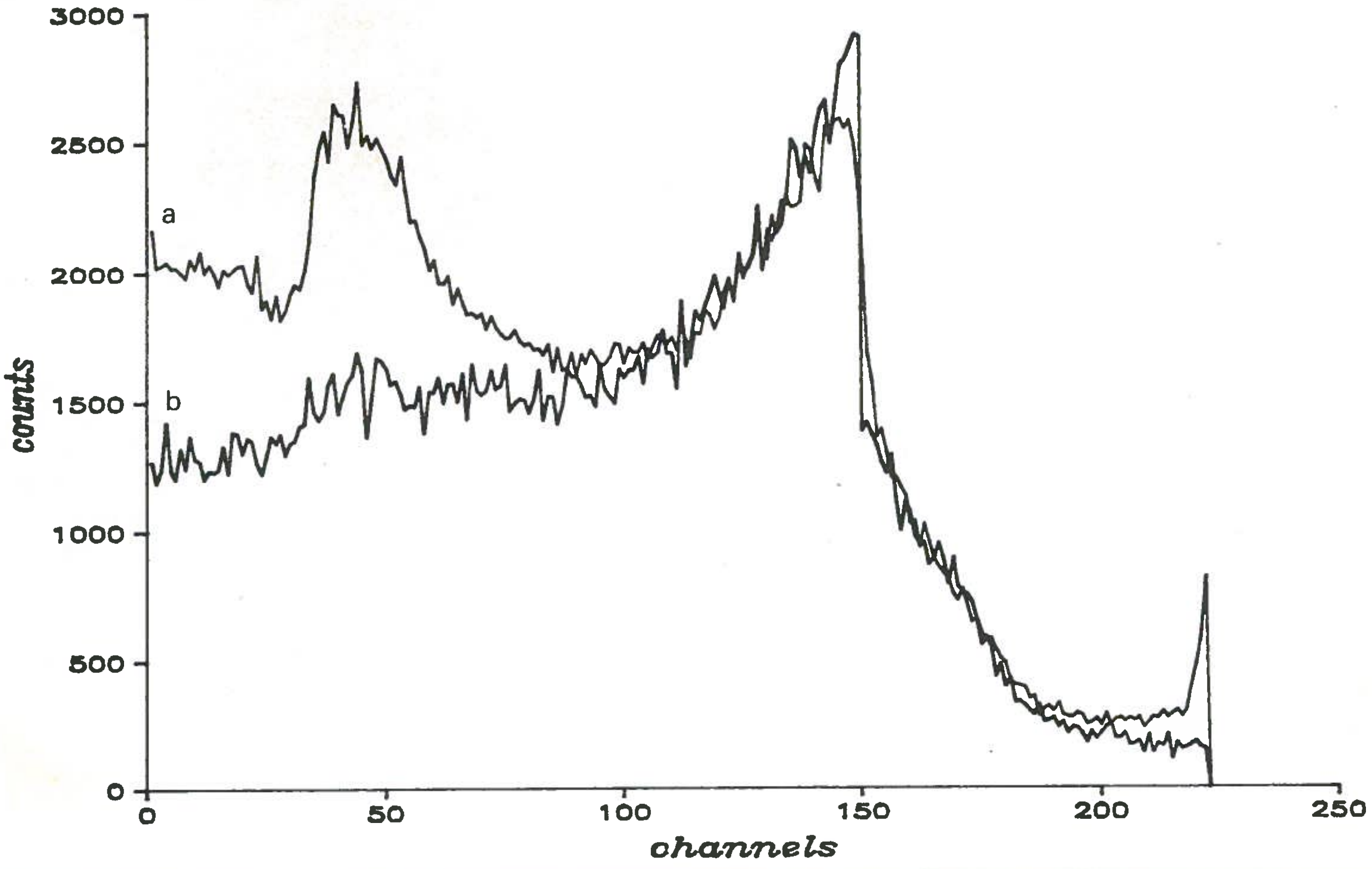

Fig. 3 Comparison between the Compton effect contribution, detected for a 137-Cs monochromatic source (a) and the corresponding response function (b).

It is possible that this discrepancy is due to the approximation introduced to accelerate the execution time of the Monte Carlo program: it considers only those photons that are generated in the solid angle, seen by the detector.

To calculate the response functions, one must know with good accurancy the shape and the dimensions of the sensible volume of the detector.

To determine the geometric volume we have used the method (3) of scanning the detector, with a photon collimated beam on both the front and the lateral surface. The gamma source (^{123}I E_{γ} = 159 keV), collimated and shielded with lead, is moved along a guide. The guide is tightly bound to the detector.

From the scanning procedure one get the shape of the active volume of the detector as in **Fig. 4.** This shape has been used to compute the response functions with the Monte Carlo program.

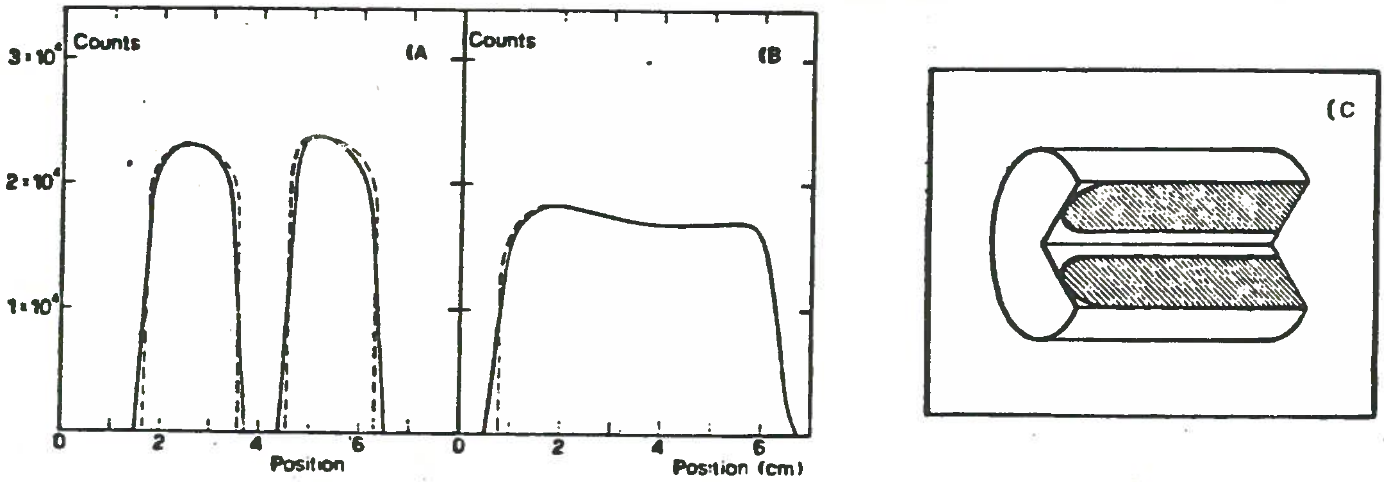

Fig. 4 Survey map of a coaxial detector shape by a scanning method: (A frontal scanning; (B lateral scanning. Continuous line: interpolation over experimental measurements. Dashed line: interpolation corrected for photon beam divergency. (C sensitive volume shape of the detector, deduced following ^{123}I ray scanning.

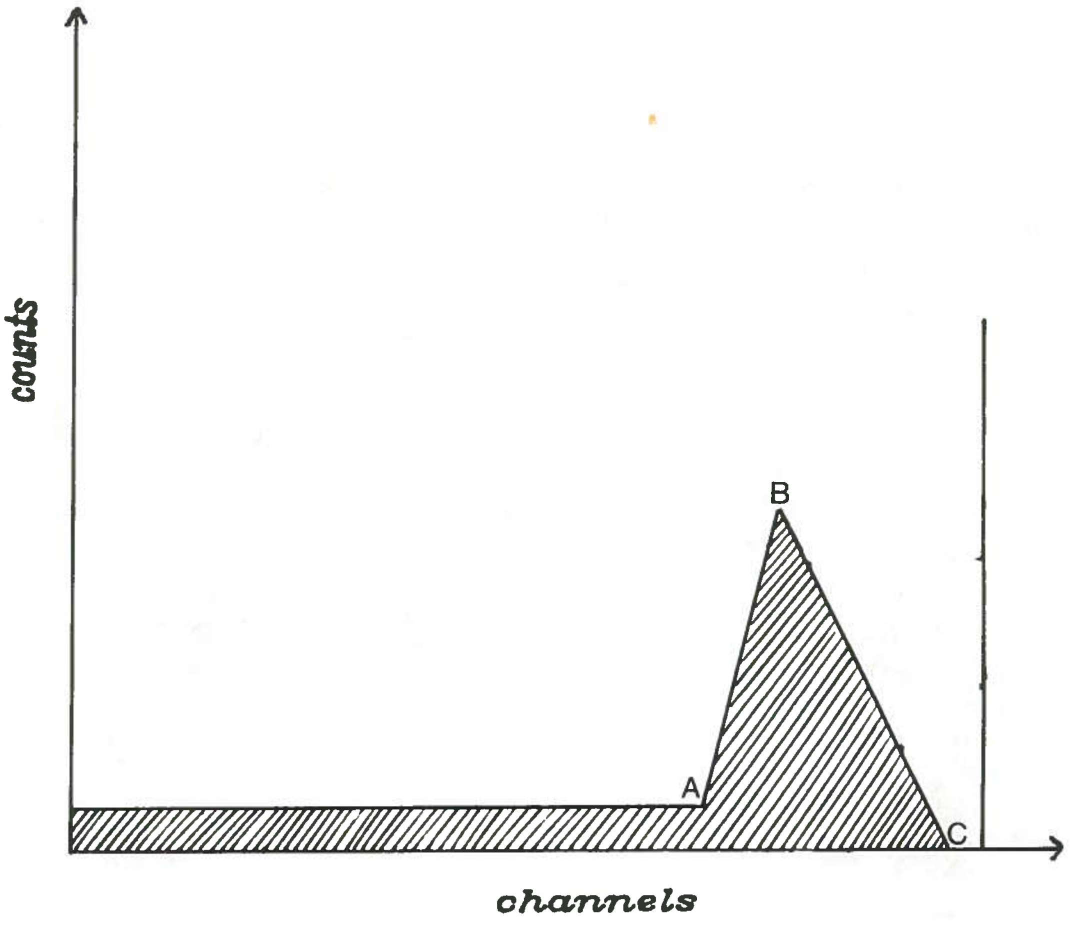

Fig. 5 Approximation of the continuum Compton of the response functions of the Ge(Li) detector.

4. - INTERPOLATION PROCEDURE

Due to the cost and length of elaboration of the Monte Carlo program and the difficult to keep all response functions in the memory of the computer at the same time, only a limited number of response functions, distributed along the energy range of interest has been evaluated. To obtain the response functions corresponding to intermediate energies, a suitable interpolation of the calculated response functions has been carried out.

As a first attempt (4) to evaluate the efficiency of the deconvolution procedure, the continuum Compton of the calculated function has been simulated with a rectangle joined to a triangle as it is shown in **Fig. 5.** The area under this figure is equal to that of the function calculated with the Monte Carlo program. The photoelectric peak is a delta, the integral of which is equal to the area of the peak itself. The intermediate functions are obtained with a linear interpolation both on the X and on the Y axis of the values of the points A,B,C, shown in **Fig 5.**

The result, shown in **Fig. 6**, of the deconvolution of a ^{226}Ra spectrum performed with this procedure has not been satisfactory. On the other hand the approximation of the response functions is too rough, and it introduces large errors in the interactive procedure of deconvolution.

A second method, based on the consideration that two response functions corresponding to different energies with the same resolution (keV/channel), have analogous shape, has then been applied.

A suitable program to distribute over N_2 channels a function originally extended over N_1 channels, mantaining constant at the same time the area under the curve, has been prepared. In this way two response functions can be distributed over the same number of channels: in general the function corresponding to the lower energy is widened to the length of that of higher energy.

To obtain the response function at intermediate energy a linear interpolation of the values of the two "rapresentative" response functions for each channel has been made.

The interpolated spectrum must be reduced so that its Compton edge is at the energy value according to the **Relation 1.**

To have an interpolated function of correct shape, the original functions must correspond to energies not too different in value (DE = 50 keV).

The **Fig. 7** shows the response function for incident photons of 475 keV, constructed with the Monte Carlo program, compared with the one at the same energy, interpolated between the functions at 450 keV and 500 keV The comparison is quite good.

In conclusion this method allows to interpolate without large errors, and is very simple. Also the deconvolution of the ^{226}Ra spectrum itself is

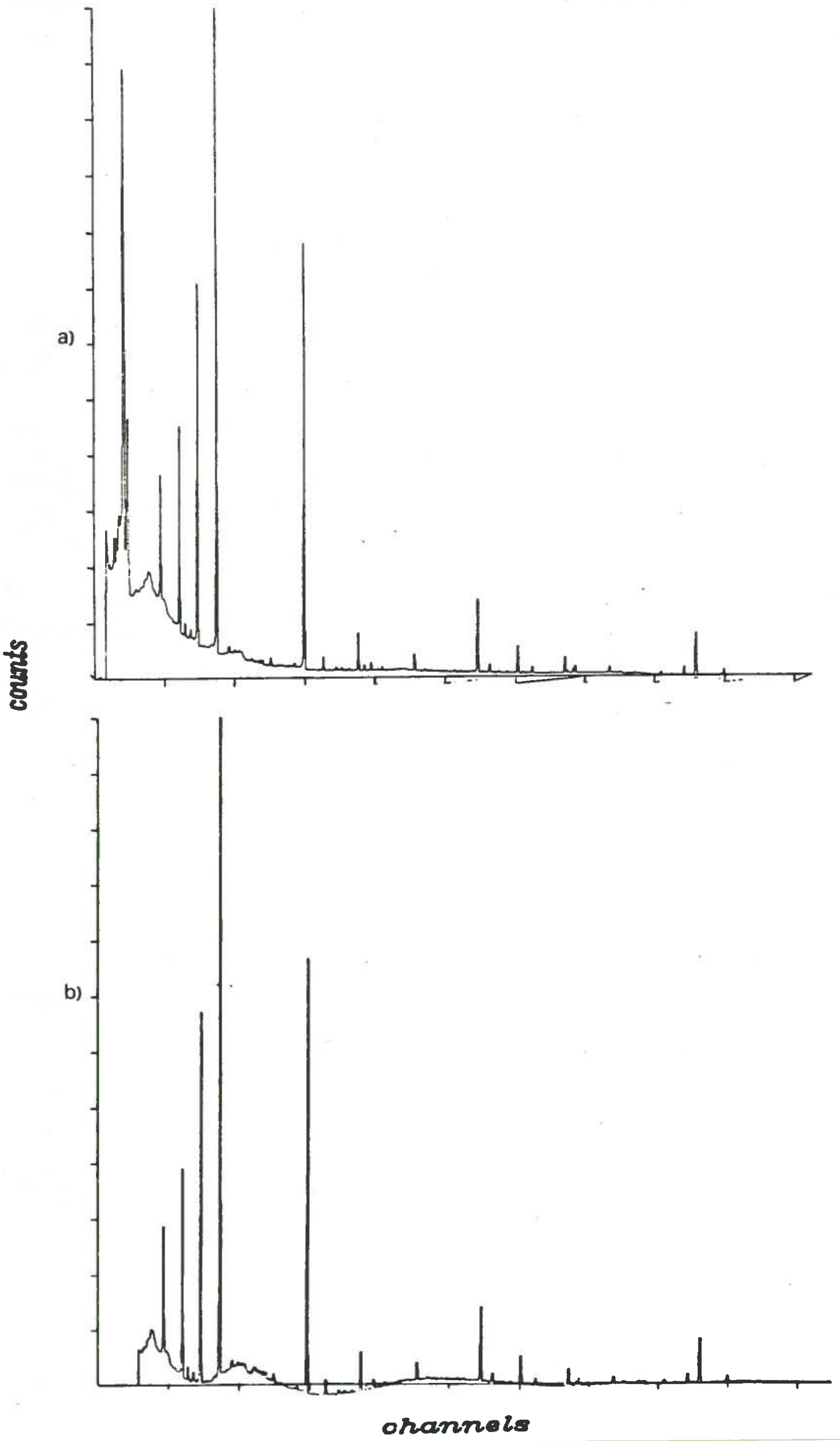

Fig. 6 a) Spectrum of a ^{226}Ra gamma source;
b) deconvolution of the previous spectrum with the approximated response functions.

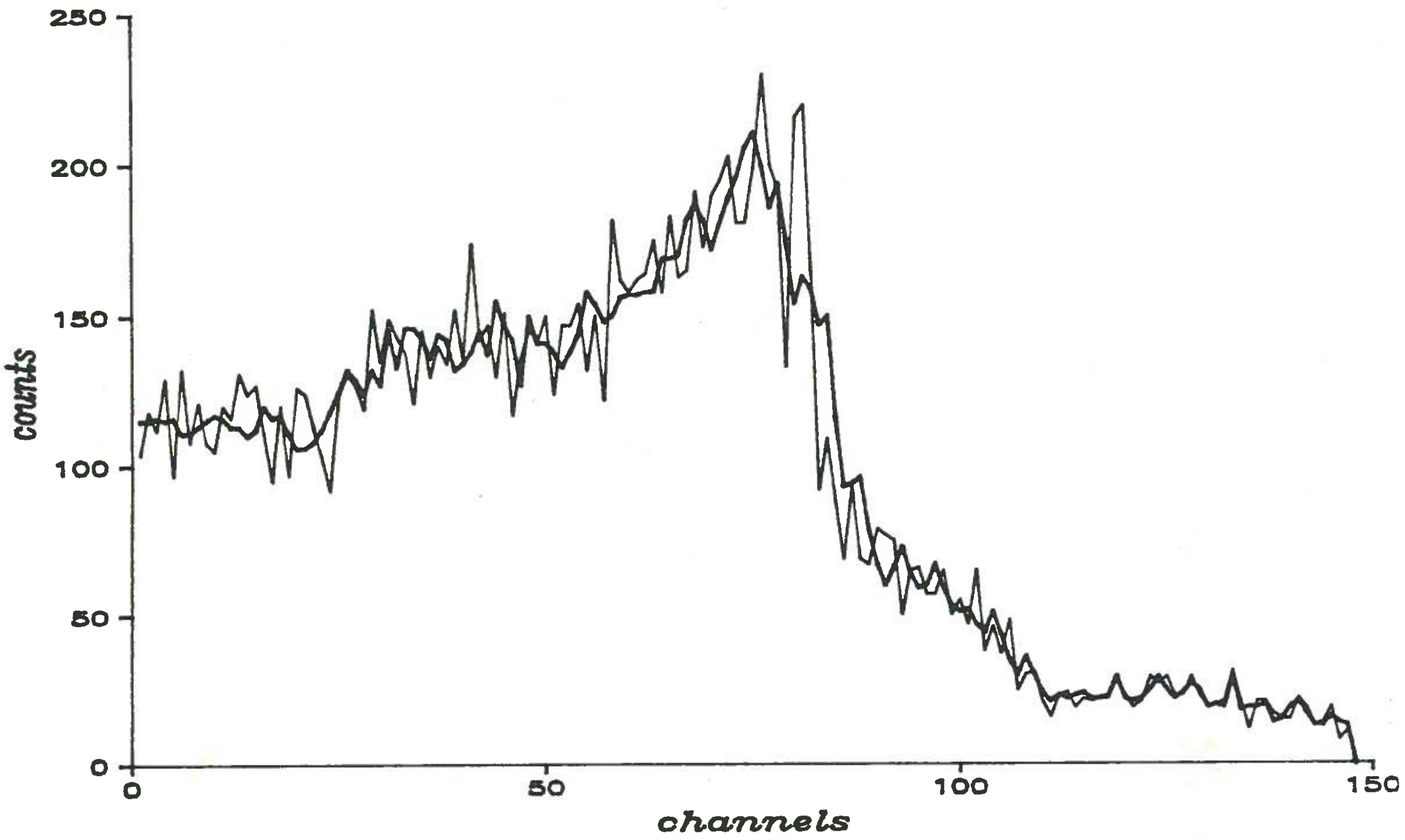

Fig. 7 Comparison between the response function for incident photons of 475 keV, constructed with the Monte Carlo program, and the one interpolated between the functions at 450 keV and 500 keV (thick line).

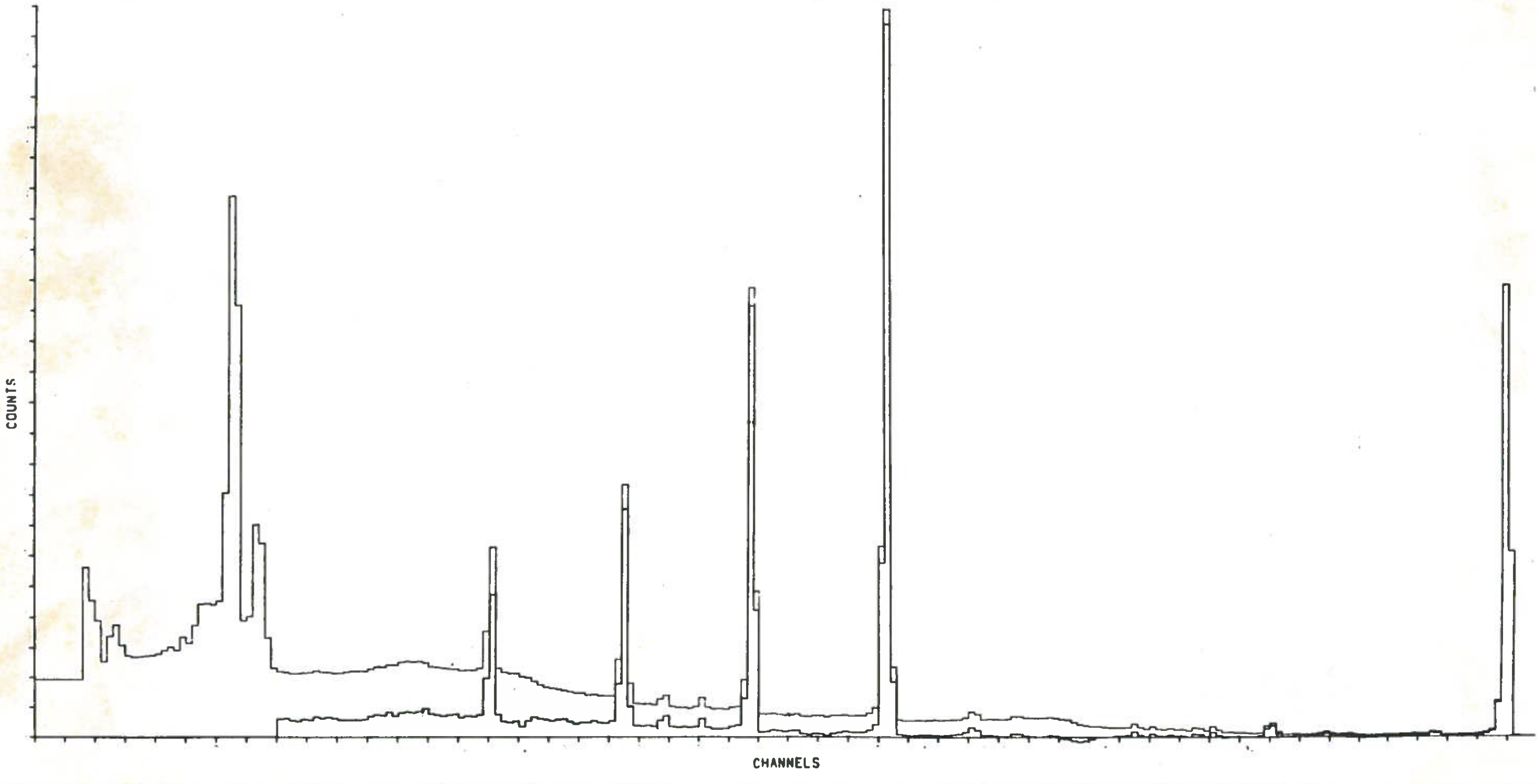

Fig. 8 Deconvolution of a ^{226}Ra spectrum with the response functions constructed with the Monte Carlo program.

much better, such one can see from the **Fig 8.** So this method has been chosen to utilize in the deconvolution technique.

5. - CONCLUSION

As one can see from the comparison between Fig. 6 and Fig. 8, the proposed deconvolution technique is correct, also if the result is not yet completely satisfactory.

From the previous discussion, it is possible that it is due to the not complete correspondence between the shape of the response functions utilized for the deconvolution and the shape of the experimental response functions of the detector to a monochromatic gamma beam. For example, the absence of the backscatter contribution in the calculated functions can justify the presence of the background in the deconvolved radium spectrum in the 0.2 MeV region.

6. - REFERENCES

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